Institut de Planétologie et d'Astrophysique de Grenoble (IPAG)

UMR 5274 Université Grenoble Alpes, CNRS

Document based on the report submitted to the Hcéres for the 2019-2020 (group A) evaluation campaign.

RESULTS

1- Presentation of the unit

Introduction

The "**Institut de Planétologie et d'Astrophysique de Grenoble"** or **IPAG** (Institute for Planetary sciences and Astrophysics of Grenoble), is one of the major research units of the Grenoble Observatory (OSUG). IPAG is a joint lab of the National Institute for Earth Sciences and Astronomy of CNRS ("Institut National des Sciences de l'Univers", INSU) and of Grenoble Alpes University ("Univ. Grenoble Alpes", UGA), created for the period 2015-2020 under joint supervision of CNRS and UGA ("tutelles"). The purpose of the present document, a self-evaluation submitted to the Hcéres, is to renew our contract with UGA and CNRS for the years 2021-2026.

The primary **mission** of IPAG is to advance knowledge in astrophysics and the planetary sciences by pursuing research at the highest international standards. To this aim we conceive, carry out and evaluate research projects, publish our results for our peers, promote our work to the socio-economic sphere, participate in education and training through research, inform the general public on our activities.

The **research themes** explored at IPAG embrace the formation of solar systems, from the initial phases of the core collapse when molecular complexity builds up, through protostellar disk physics and chemistry, up to the study of exoplanets. We also work on accretion-ejection processes around young stellar objects and compact objects (neutron stars, black holes). In planetary sciences, we study Sun-Earth interactions, planetary subsurfaces, small bodies in the solar system, and the chemical evolution of primitive matter.

Our activities obviously include astronomical observations, but also laboratory measurements, high performance computing, as well as the design and operation of cutting-edge **instrumentation** for space missions and ground-based telescopes, notably for the future European Extremely Large Telescope (ELT). Our expertise includes adaptive optics, integrated optics, interferometry, infrared detection, and radars on space probes to study the structure of Solar System bodies.

We thrive thanks to our local, national and international **collaborations**: with other labs, universities, research institutions (CNES, ESO, ESA, CEA, ONERA), and companies (SOFRADIR, Thales, Airbus). In addition to our research publications, we are keen to patent our inventions and to initiate startups (Alpao, RSS, FLI). We benefit from funding from various agencies, notably the French National Research Agency ("Agence Nationale de la Recherche", ANR) and from the Horizon 2020 program of the European Union.

With more than 30 scientists employed by the University (CNAP, CNU), IPAG is strongly involved in **teaching** and training at the Université Grenoble Alpes. We welcome PhD students from all countries and host every year more than 30 students on internships. We propose many activities to engage with a wider audience on astrophysics and planetary sciences: from telescope nights at our institute to the planetarium project at the Moulins de Villancourt.

History, localisation of the unit

IPAG was created on January 1st, 2011 from the merger of two laboratories: LAOG (Laboratoire d'Astrophysique de Grenoble) and LPG (Laboratoire de Planétologie de Grenoble). It occupies two premises situated on the east side of the university campus since 2015 (see highlights). The main building (2500 m^2), called OSUG-A is where the Odyssey, Exoplanètes, Sherpas teams, the main part of the support group and the salle Manuel Forestini are located. It is at 414 rue de la piscine. The Planéto and Interstellaire teams together with part of the lab administration are in the so-called OSUG-D building at 122 rue de la piscine, which comprises 1600 m^2 on the 2nd and 3rd floors of OSUG D proper and on the third floor of Phitem-D, both linked by a covered gateway.

Figure : *IPAG Buildings (OSUG-D/Phitem-D, left; OSUG-A, right).*

Structure of the unit

IPAG research is structured around five **scientific teams**. The scientific teams investigate

- the small bodies, atmospheres, surfaces and sub-surfaces of planets in our Solar System (Planéto),
- the detection and characterisation of exoplanets and debris disks (Exoplanètes),
- the formation of stars and their planets (Odyssey),
- the physics and chemistry of the interstellar medium, the origin of molecular complexity (Interstellaire),
- accretion-ejection, high-energy emission in young stellar objects and compact objects (Sherpas).

We also have one **transverse team** to federate and stimulate IPAG R&D efforts around

- new instrumental concepts and detection techniques (Cristal).

The objectives of the scientific teams are detailed in their specific sections of this document. The next contract will see Cristal evolve to a fully-fledged scientific team and the addition of a new team, Spectre. This is detailed in 2- Structure, workforce and scientific orientations.

IPAG has organised its technical and administrative staff ("ITA") within a "**support group**". These staff members are not attached to scientific teams but to six services, under the supervision of the technical director of IPAG. Research engineers ("ingénieurs de recherche"), who make essential contributions to instrumental research at IPAG, are also members of scientific teams where appropriate. The administrative and computing services ensure every day that IPAG operates smoothly and effectively. The technical services develop expertise on topics such as high-contrast imaging and the associated data processing, real-time wavefront analysis, large sized near infrared detectors, deformable mirrors, opto-mechanical design, system integration of ground and space-based instruments.

The **administrative** service handles the administrative, accounting and financial management of IPAG personnel and projects. The service plays a central role in the life of the institute: reception, order processing, contracting, inventory, tenders, logistics, workshop or conference organisation, staff training, etc. The service works in close collaboration with the services of the regional CNRS center (DR11) and those of the Grenoble Alpes University (services centraux).

The **computing** service prepares, manages, secures and maintains the computers, systems and networks indispensable to the activities at IPAG; provides support to projects in data acquisition, control-command of detectors, data analysis and simulation; collects, organises, provides information and a document management system to IPAG personnel. The service is the contact point for our supervising institutions (CNRS, UGA) and partners for all matters related to networks and computing. The service works in close collaboration with the OSUG computing service for pooled actions between the labs of the Grenoble Observatory, and with the Grenoble SUMMER data infrastructure GRICAD.

The **instrumentation** service helps design and realise the instrument systems and subsystems developed at IPAG. The service formulates the technical specifications of these systems; develops test benches, notably optical benches, to assess and validate their performance; participates in the definition and characterisation of the detectors to use; helps write out the requirements; consults in house or with industrial partners to plan the construction of the instrument ; contributes to the integration and testing of the completed instrument at IPAG or on site. The service also supports the chemistry (mass spectroscopy, meteorite analysis) and physics (spectroscopy, goniometry) laboratories present at IPAG, some of which operate in cold environments.

The **mechanics** service assists the realisation of new instruments from their conception to their actual delivery. Mechanical aspects can be critical and must be considered carefully to enable the design performance to be achieved, for instance to ensure stable optical paths. The service covers micro-mechanics, cryo-mechanics, up to the conception and sizing of large structures such as that of VLT/SPHERE. The service manufactures in house or takes charge of following, testing, assembling, integrating subcontracted elements.

The **electronics** service takes on the research & development, the implementation of projects in the areas of digital or analogue electronics for ground-based or space-based instrumentation. For instance: designing and fine-tuning actuators and sensors for ELT instruments, from control electronics to the first layers of software control; FPGA developments for real-time signal processing with applications to space-based radar tomography or to new detectors developed by industrial partners. Most of these projects are carried out within international consortia. The service also assists projects in spectroscopy and microscopy carried out at LiPhy.

The **project support** service is a new endeavour to regroup administrative staff managing large projects that are IPAG-based. These projects typically involve complex collaborations with several outside partners and require dedicated staff to assist the PI in managing the project, reporting, scheduling, etc. The last 5 years have seen a major rise in project-based research at IPAG. The organisation of our support services is likely to continue to evolve in recognition of this context and the new demands it places on IPAG staff.

Unit's workforce and means

Workforce

Around 160 people currently work at IPAG, roughly consisting of 60 staff scientists and professors, 30 staff engineers, technicians, administrative personnel ("ITA"), and 70 contracted personnel including around 20 postdocs, 30 PhD students, 10 fixed-term contract ITA, 10 long-term visitors, apprentices, etc. According to the May 2019 Labintel data, IPAG is in the same tier in terms of size as laboratories like Lagrange, IAS or IAP. IPAG has the highest ratio of non-permanent to permanent staff of all astronomy labs in Labintel (0.8 compared to a median of 0.6). IPAG scientists have successfully attracted funding for their projects, possibly resulting in a somewhat higher proportion of postdocs and PhDs than elsewhere. Although we have large commitments to instrumentation projects, we punch above our weight given our (permanent staff) ITA to researcher ratio of 0.5, which places IPAG in the bottom tier of astronomy labs (median 0.7). One reason is our ratio of non CNRS (i.e. University) to CNRS ITA staff of 0.2 compared to a median of 0.8. We've partly compensated by having 5 to 8 people on fixed-term ITA positions (CDD) using our own resources, with additional support in a few cases from CNRS and Univ. Grenoble Alpes. For the first time, we also recruited an ITA on an open-ended contract with Univ. Grenoble Alpes (CDI) to avoid the loss of his critical expertise on radars.

The **understaffing in ITA personnel** has aggravated during the past five years with the ITA group losing 8 permanent staff members from 2014 to 2018 (see Table). We have been going down steadily in numbers since 2013, when the number of permanent ITA peaked at 37. We currently have 28 ITA staff on permanent positions. Retirements project us down to 23 positions in 2024. The downward trend affects all categories, BAP C (instrumentation), J (administration), E (computing). We have fixed-term positions on all these categories of professional expertise. Several factors are identified to explain this trend, aside from natural movements to/from labs due to personal career choices: uncompensated retirements, departures for positions with a competitive edge compared to ITA CNRS positions (e.g. ESO, INSU Management), pooling (mutualisation) of computing support services with OSUG. We are fully aware that the dearth in ITA recruitments is general to CNRS. Yet, the number of projects and, more importantly, their complexity has not abated. Indeed, although we are fortunate to have had an external ITA recruitment approved by CNRS in 2018, the position is primarily to manage a national structure, EFISOFT, unifying French efforts around ELT control-command. Fixed-term contract ITAs provide much needed help, provided funding is available for this purpose, but cannot replace long-term experience. The time and effort needed for their recruiting, training and integration in the lab cannot be neglected. The impact on our lab has been increased pressure on the support group and management.

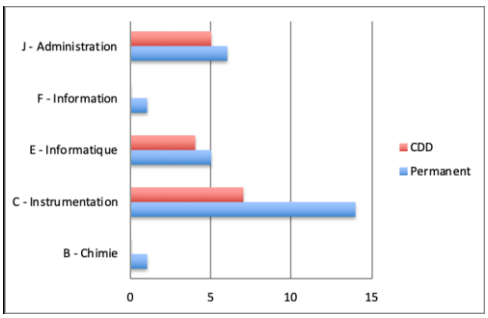


Figure : *Staff in the support group for permanent and fixed-term contracts (CDD), according to the nature of the professional expertise ("BAP").*

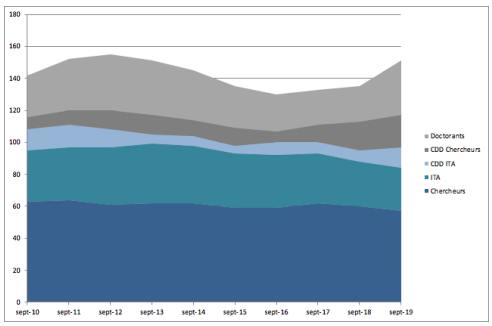


Figure : *Evolution of IPAG staff, including PhD students (doctorants), postdocs (CDD chercheurs), fixed-term ITA/BIATSS (CDD ITA), permanent staff (ITA/BIATSS, Chercheurs). Apprentices, visitors, personnel on detachment are not included.*

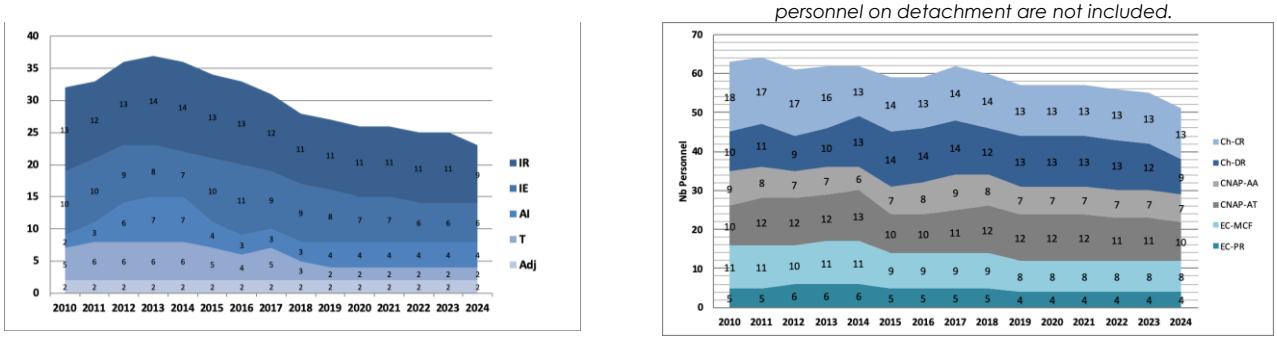


Figure *Evolution of permanent staff, for the support group* (left) *and for researchers (including emeritus,* right*), per category. A fixed retirement age assumption has been made in to extrapolate numbers on 2020 and onwards.*

After a continuous rise until 2011, the **population of permanent researchers is now stable** around 60, allowing for fluctuations as researchers come and go on extended leaves to institutes abroad, especially to the CNRS international unit (UMI) in Chile. We've had 3 new CNRS researchers and 2 new CNAP astronomers recruited since 2014, for 5 retirements. One of the CNAP astronomer is currently working for IRAM ("mise à disposition"). A third CNAP astronomer will join IPAG starting in January 2020. On average, this is about 1 new researcher / year, half our intake over the previous contract period (2/year on average). Obviously, the general reduction in CNRS and CNAP positions in the past years is also affecting us. At the University, IPAG has not fared well. IPAG has also consistently pushed for an associate professorship on "the origin of planets and conditions for their habitability" over the past years, without success despite the position being ranked as the first priority of PAGE last year. Our last associate professor recruitment dates back to 2013. We've had no associate professor recruited with teaching duties at "Phitem" (physics) since 2009, although we've had three Phitem professors leaving IPAG for other positions or retiring. Promotions are also very worrying: only one IPAG associate professor was promoted through a 46.3 professorship in the past 5 years despite a large pool of excellent candidates for professorships. We are very concerned that the lack of perspectives may lead talented associate professors to leave IPAG.

The previous Hcéres committee had pointed out that "*all but one of the 10 researchers recently recruited at IPAG defended their PhD thesis in Grenoble.*" Three of our 6 new researchers defended their PhD thesis in Grenoble. This is a significant change compared to the previous contract period, in phase with the committees wishes. Inversely, some of our PhD students have obtained permanent positions in other labs. The current balance seems fair to us: we are keen to remain attractive for "outside" recruits but we are also keen to encourage our local students by providing them with long-term prospects. In addition, the recruitment process for permanent positions requires that strong ties are maintained with the proposed host laboratory over the course of several years, naturally favouring locals. Besides the new hires, we have also benefited from the arrival of one CNRS scientist and one CNAP scientist who moved from the Paris area. Such transfers have a very positive impact on the lab by opening up new research lines connected to our main topics (Gaia, massive star formation).

We've had 37 postdocs at IPAG over the evaluation period, 22 of which were foreigners. They have an important role as international "ambassadors" for our laboratory. We have recently been paying closer attention to their experience at IPAG, setting up a yearly interview with their team leader, discussed in the "comité de direction élargie", to identify what we do well and what we can improve. The number of postdocs is heavily dependent upon project funding from the ERC and ANR. There are few other recurrent sources of funding for postdocs. Univ. Grenoble Alpes has provided funding through its cross-disciplinary programs "Data Institute" and "Origin of Life", but these are not recurrent and their long-term evolution within the UGA IDEX is uncertain. CNES has also provided funding for 2 postdocs in the past 5 years.

IPAG hosts or has hosted 75 PhDs from January 1, 2014 to June 30, 2019: 27 were already ongoing as of January 1, 2014 and 48 new PhDs have started since then. About 50% of our PhD students come from an MSc in Grenoble, 10% come from abroad with their own funding, 40% from elsewhere in France. IPAG scientists have affiliations with three doctoral schools: Physics, TUE (Earth Universe Environment, mostly Planéto scientists) and EEATS (photonics, some Cristal scientists). Most of our students are affiliated with the physics doctoral school. About 50 students in all areas of physics applied in 2018 for the 17 PhD contracts available from this school (14 for Grenoble, to compare to its 430 HDR scientists). These contracts, open to all subjects, represent ~15% of the yearly intake of new physics PhDs in Grenoble (~100/year). IPAG mirrors this with 1 or 2 PhDs/year funded by doctoral schools and 7-8 PhDs/year funded by projects, with large fluctuations. At present, there are currently 35 PhDs at IPAG for about 45 HDR scientists (habilitated to supervise a PhD and currently in activity at IPAG). With 14 new HDRs over the period, IPAG scientists have clearly understood the benefits of defending their HDR as soon as possible.

Most PhDs are funded by ANR or ERC projects awarded to scientists or through CNES, UGA or CNRS calls targeting specific themes or countries. This fraction is constantly rising. One unexpected evolution is that PhDs are increasingly funded by combining funds from multiple sources, up to four different sources in the most extreme example seen at IPAG. This certainly benefits funding bodies, who can list more funded PhDs. At the IPAG level, on the positive side, this does encourage cooperation between scientists. Indeed, more and more PhDs seem to be co-supervised. However, this also multiplies applications (and their review) for scientists, poses timing difficulties when funding sources work on different calendars (obviously unrelated to the academic one), and strongly strain administrative staff who must deal with the kafkaian situations that often arise from such financial engineering.

The previous Hcéres committee had recommended that "*the number of PhD students is still low, and the IPAG management should do its best efforts to attract them (and find the corresponding funding)*." This recommendation has been debated. Some PhD students feel that an increase in the number of students is not justified because the number of permanent positions in astronomy is not growing. Some scientists feel that quantity should not prime over the quality of the PhD projects that they offer, notwithstanding that current funding perspectives do not allow significantly more PhDs to be funded. In the end, despite our best efforts, the average intake (9-10/year) is unchanged from the previous contractual period, and would have been lower without ERCs.

Out of the 43 PhD students that have left IPAG over the period, 47% are currently postdocs (26% abroad, 21% in France), 26% have a position in the private sector, 19% have a position in the public sector and 9% are looking for a job or we have no information.

Figure : *Personnel at the 2019 Journées du labo*

Budget

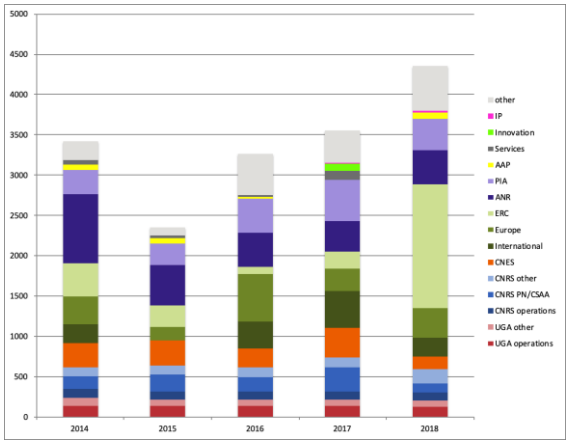


Figure : Evolution of contributions to the IPAG budget, rounded off to the nearest 10 kE for clarity.

The **consolidated budget** of IPAG is about 11.4 ME/year, including about 8 ME/year in permanent staff salaries and a typical "financial" budget of 3.4 ME/year.

The table shows the various contributions to the financial **budget** and their evolution with time. The blue cells highlight resources ("ressources propres") attributed directly by CNRS and Univ. Grenoble Alpes. The recurring part for operating IPAG ("fonctionnement") continues to be eroded, from 139.5 kE to 125.5 kE (UGA) and from 110.8 kE to 104 kE (CNRS), even though our previous report pointed out that IPAG was already receiving 30% less funding than LAOG and LPG combined. All the other lines relate to project- or contract-based funding. "PN/CSAA" are projects submitted every year to INSU for funding. "UGA other" includes University funding for visiting professors and OSUG funds for observation services. "CNRS other" includes transfers from other labs for PN projects, one-off support for specific actions. The green cells highlight funding from contracts to IPAG. "International" includes contracts with ESO (Sphere, NAOMI) and ESA (CONSERT, MASCOT, AIDA). "Europe" includes funding from all H2020 programs except ERCs, which are listed separately. Similarly, ANR project funding is separated from PIA funding (Labex OSUG@2020 and FOCUS). "AAP" includes funding from other public organisms, essentially FUI funding since we placed CNES on a separate line here. "Services" includes mostly funding for conferences, and some contracts for expertise. "Innovation" includes funding for nurturing ("maturation") programs e.g. with our local SATT Linksium. "IP" are resources from licensed Intellectual Property. "Other" is mostly funds carried forward from the previous year.

The major grants are the Labex FOCUS, the 4 ERCs (5 including MHDiscs starting this September), the ESO contract for NAOMI, the ITN ACO, the two European Research Infrastructures (Europlanet, Opticon), H2020 projects (SCARBO, StarFormMapper), ESA contracts, etc. However, funding for the UGA CDP "Origin of Life" does not appear because it is handled directly by Univ. Grenoble Alpes IDEX (also meaning that this large project brings no overheads for the lab). We also note that we managed 25 ANR, 17 of which as PI, from 2014 to 2019, a slight improvement on the previous period (21 ANR with 2/3 as PI in 2009-2014). A few IPAG scientists also benefit from funding from two ERCs hosted at other labs.

The operating budget of IPAG has large fluctuations as contracts come and go (3.4+-1 ME in the last 8 years). The operating budget hit a low point in 2015 (2.4 ME) that had been predicted in our previous report: SPHERE (-0.2 ME) and several ANR (-0.5 ME) ended at that time without new projects coming in, a reminder of how quickly our financial situation can turn and how difficult forecasting can be. The budget has increased since then because IPAG scientists are pro-active and successful in obtaining funding from a variety of sources, not just ERC projects. Overall, 33% of the budget comes from international agencies (international, Europe, ERC), 28% comes from national agencies (ANR, LabEx, call for projects), 27% from organisations (CNRS, Univ. Grenoble Alpes, CNES) and 13% from other sources.

An annual funding of 250 kE is available for IPAG common operations from Univ. Grenoble Alpes and CNRS. This is insufficient to cover the basic expenses required to operate the lab, what we call our **common budget**. Typically, we have fixed expenditures of 120 kE given our "SHON", the University "renting" that in effect balances its contribution to IPAG operations, and we require about 25 kE for the computing infrastructure, 25 kE for printing, copying, telephone, mail, 20 kE to cover PhD jurys and seminars, 20 kE for building maintenance, 15 kE of lab & technical equipment, 12 kE for journal access ("g@el"). In addition, we wish to offer basic support to the scientific life of teams and services (15 to 25 kE/year), contributions to equip staff with laptops (0.6 kE per person every 5 years), contributions to the institute life (PhD days, weekly pre-seminar coffee, meal for IPAG general assembly, about 7 kE/year), special expenditures (Lab Days, IPAG move from OSUG B to OSUG D), maintenance of our common IPAG car (5 kE/year), renewing furniture or decoration (2 to

10 kE/year), official missions to INSU (3 to 10 kE/year), contribution to training (2 kE/year), and so on. Most importantly, this also does not cover hiring administrative staff to handle the additional load brought about by large, complex projects.

In order to provide these services, IPAG takes an **overhead** on the projects it hosts. Our official rule, presented to the lab council and published on the intranet, is to levy 10% of the total amount arriving at IPAG, excluding expenses to pay personnel (PhD students, postdocs). This is tricky to implement as contracts have very different governing rules. For instance, this is not applied to ANR projects as the lab overhead is strictly regulated, CNES also has its own rules, etc. Another difficulty is that personnel expenses may vary during the project lifetime. Once all these constraints are considered, the average levy on projects has been about 130 kE/year since 2014. Thus, the effective levy is about 5% on all contract-based funding. We are working on finding levy rules that would be easier to implement. For instance, we are now applying a flat rate of 7% on newly-submitted ERCs. In all cases, the lab overhead is always clarified and settled with the project coordinator in a CAMPI meeting before the start of the project.

Altogether, the common budget of IPAG is around 380 kE/year, about 11% of the average budget. The detailed budget is presented every year to the laboratory council for discussion.

Scientific policy

The main scientific questions that we wish to address are:

- What is the history of our Solar System? How did the diversity of bodies that compose it come about? What are the chemical and physical processes at work in these bodies? Can this be transposed to other planetary systems ?
- How diverse are exoplanets? How are they organised into planetary systems? Can they be grouped into families with common properties? Which ones could harbour life?
- What are the conditions for the formation of stars and planets? How do young stars interact with their environment? How do protoplanetary discs around young stars evolve and form planets?
- What are the physical and chemical processes that precede and accompany the emergence of large-scale structures, massive stars, complex molecules? How much do we inherit from interstellar processes?
- How is matter transported in accretion discs around young stars and compact objects? How is part of the matter ejected in winds and jets? Why are some particles accelerated to relativistic energies?
- Which new instrumental concepts can address these scientific questions and open up discovery space? What technologies or methods need to be investigated and mastered to bring them about?

Although this list reflects the current scientific team organisation, each group of questions is not exclusively addressed by one scientific team. Indeed, there are many overlaps between teams and it has always been IPAG policy to encourage this. Our teams emphasise different approaches to address those questions: observation, data analysis, laboratory measurements, instrumental research, modelling, theory, simulation. It is a strength of IPAG that all these approaches are pursued here and able to interact with each other. We believe the above forms a coherent backbone to research at IPAG, without being exclusive of other lines of inquiries: questions change, opportunities arise. The merging of LAOG and LPG has brought many synergies that IPAG capitalizes upon.

We aim our **research** to be at the forefront of the international science. The previous Hcéres report rightly encouraged us to "*be ambitious (...) international visibility should be a priority (...) ERC applications should be encouraged*". The last years are undoubtedly a success by this simple measure, given our ongoing (or soon to start) ERCs: DOC (advanced), SPIDI (advanced), SOLARYS (consolidator), MHDISCS (consolidator), EXTRA (starting) compared to 1 ERC grant in the previous contract. Remarkably, each scientific team hosts one ERC. Success does breed success: these ERCs stimulate the ambition of our researchers. Several other applications have made it to the second round of the selection process, a promise for the future. However, ERCs are not the only indicator of our international visibility. The newly-started ITN AstroChemical Origins piloted by IPAG, the projects that we conduct for ESO (SPHERE, NAOMI) or ESA (CONSERT, MASCOT), the COST actions "our AstroChemical History" and "Polarisation as a tool to study the solar system and beyond", our technical contributions to major international infrastructures (ELT/MAORY and HARMONI, IRAM/NIKA2, CTA, CFHT/Spirou), our participation in European Research Infrastructures (Opticon, Europlanet, ESPAS), our formal partnerships with NASA (New Horizons, Europa Clipper) or JAXA (Hayabusa-2), readily demonstrate that IPAG is present on the international stage when it comes to major projects. Indeed, one third of our funding comes from international sources (see above). We have a healthy seminar program (>30/year) with many international speakers. Our lab successfully attracts foreign scientists on extended stays (>1 month). We've had 28 in the past 5 years, taking full advantage of calls for visiting professorships (see section 2). Inversely, we have

IPAG scientists invited abroad for extended stays, establishing exchange agreements with labs in various countries. The "Planeterella" aurora demonstrator developed for outreach has been taken up in many countries. Our researchers also lead major observation programs (e.g. SOLIS, CHESS, ASAI, ALMA-IMF, FAUST, MERITS, etc), successfully apply for European tier-0 computing time (PRACE), organise major international conferences and schools in their fields (e.g. physics & chemistry of the ISM, plasma astrophysics 2017 and 2019, microquasar conference, Rosetta SWT 51, etc). Perhaps the most telling sign of the value of our research is the sheer number of reviews that we are asked to provide for international agencies. This has exploded in the last years, perhaps worryingly so.

The conception and development of cutting-edge **instrumentation** is a key element of our strategy to be at the forefront. We build on our capacity for long-term R&D (e.g. on integrated optics) and the high-level expertise of our technical group. The ITA staff is organised in services rather than formally attached to scientific teams or projects to encourage the sharing and broadening of expertise. Keeping our scientific objective, our commitments to major instruments and our R&D projects in phase is a continuous challenge. We followed the recommendation of the previous Hcéres committee, the "*transformation of Cristal into a transverse axis, in support to scientific teams*". We propose to evolve towards another organization (see project) as we gear up for the next generation instrumentation for exoplanet imaging, including the planet finder for the ELT (PCS). Indeed, the previous Hcéres report pointed out that "*a roadmap should be developed for attaining this long-term goal, which will include contributions to the first light ELT instruments*". Existing and potential IPAG contributions to the ELT have been assessed in 2017-8 by an internal working group. This clarified the objective and extent of our involvement in MAORY, HARMONI and MICADO, a first step. It also recommended to push for an IPAG-led high contrast (HC) mode for HARMONI. This second step is on its way with a recent funding from Univ. Grenoble Alpes. Going towards a PCS instrument will require further advances in active coronography, high-contrast imaging and spectral resolution, for which R&Ds have been identified. Some will have to be proven on sky and/or will participate in upgrades of current instruments (e.g. SPHERE). The first to be funded (by OSUG@2020) is HDC, which is exploring high contrast and spectral resolution with a VIPA spectrometer. Pursuing these objectives will be a major goal of the future Charm team.

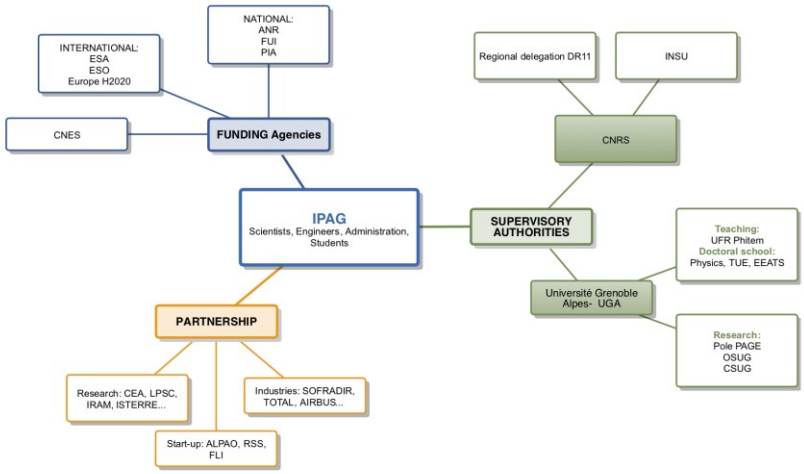
Innovation is inherent to cutting-edge instrumentation. We nurture our links with the 3 startups that are spin-off companies from IPAG (Alpao, RSS, FLI). Three IPAG engineers spend 20% of their time each as experts for Alpao and FLI ("concours scientifique aux entreprises"). A convention exists with RSS with regards to loaned equipments. We have long-standing collaborations with CEA-Leti and SOFRADIR on integrated optics and detectors. New instrumental concepts (Swifts, SPOC) explored with initial funding from the Labex FOCUS and OSUG@2020 have led to major research programs in collaboration with industrial partners SCARBO (Airbus), ANAgRAM (RSS), Imagaz (Total, SOFRADIR), ImSPOC-UV (Pyxalis). We have ongoing technology transfers ("pré-maturation") programs with CNRS on other patented or pre-patented technologies to get them to TRL 3. One of them has now been selected for a maturation program with Linksium, our local SATT (Société d'accélération du transfert de technologie). Innovation also includes training future highly-skilled scientists at the frontier of research and technology. Thanks to CNRS and FOCUS funding, we've had five apprentices from engineering schools for long stays in our services during their studies. We've found this new activity (for us) very rewarding.

Indeed, as a University research lab, we are committed to **teaching and training** future generations to the highest level. We've had nearly 100 Masters students come for internships over the evaluation period, not only from Grenoble, and not counting many more at the bachelor level. Indeed, some of our PhD students initially discovered our research on "stages d'excellence" (L1, L2). IPAG staff are involved in teaching courses offered through the UFR Phitem, Grenoble INP and, to a lesser extent, the IUT and the doctoral schools. We teach courses offered in the first and second year of the Physics Master, including lab experiments located at IPAG (TP CESIRE). We are responsible for the astrophysics specialty of the Master 2 in Physics ("parcours astro"). The students following the courses of this "parcours" are hosted by the lab in OSUG A, where we provide classroom, textbooks, computing equipment, etc. This proximity is widely seen as very positive by both staff and students. Various introductory courses to Astrophysics are also given at earlier levels (license) but IPAG contributions are less visible. A concern is whether the number of students (5-10) attending the M2 "parcours astro" is on a decreasing trend, albeit with much fluctuations. This may end up threatening the continued existence of this option. A possible outcome would be a forced merger with another "parcours" (e.g. "physique subatomique et cosmologie"), leading to unsatisfactory compromises and gaps in the astrophysical training of students. A possible mitigation is to share courses with other M2 in astrophysics, as is already the case between Grenoble and Strasbourg, with two courses currently given by video teleconferencing. We are also able to offer these students high value on-site training at the IRAM 30m dish or the Observatoire de Haute Provence (OHP).

We are also very active in engaging with the wider public through open courses and **outreach** activities. We created the MOOC « A la recherche d'autres planètes habitables » (searching for habitable worlds), a large success with more than 7000 registered users in two sessions (2016, 2018). The MOOC has also been used in private sessions by high school teachers of the Grenoble region as part of their continuous education plan. Our scientists are engaged in a large number of both recurring activities and special events for public

outreach, including a long-term commitment to the future metropolitan center for scientific culture (opening 2021). Our policy is that these activities are coordinated by OSUG who has dedicated staff for this. A concern is that we do not necessarily have a full appreciation of all our outreach activities and that we may not promote IPAG well-enough. We've recently appointed a "communication coordinator" to help us with this, as detailed in the next section.

2- Presentation of the unit's research ecosystem



The "**Observatoire des Sciences de l'Univers de Grenoble**" (OSUG) is our major local partner. OSUG groups all the scientific workforce in the Univ. Grenoble Alpes area on universe sciences i.e. about 400 researchers in 7 laboratories, with IPAG the third largest after ISTerre and IGE. The IPAG director participates in the monthly meetings of the OSUG "comité de direction". An IPAG scientist is deputy director of OSUG for observations and other IPAG scientists are present in its various commissions and its scientific council. OSUG is a key partner for three reasons.

First, the statutory teaching and service duties of all IPAG astronomers (CNAP personnel) are administered by OSUG. More generally, OSUG manages the observation services that involve IPAG personnel. In particular, OSUG manages a data center that includes the SPHERE-DC data base and analysis service, the SSHADE-F-GhoSST European database of spectroscopic data, the MOIO data base of software for optical interferometry. There is very good coordination with OSUG on these key elements of our scientific policy.

Second, OSUG is where we mutualise our computing and communication services with other laboratories, encouraged in this direction by INSU.

- Public communication is handled by OSUG staff (on fixed-term contracts) who host our website, advertise our press releases, organise public events, etc. Our IPAG "communication coordinator" (Philippe Delorme) directs people to the right contacts at OSUG and tracks activities. Together with OSUG, we have a long-time commitment to the project for a **metropolitan center for scientific culture** (link), located in Pont de Claix (opening 2021). IPAG scientists commission the future permanent exhibition on astronomy and space science (Solar system, Milky Way, formation of stars ans planets, exoplanets, ...) and serve as scientific advisors, with clear gains for IPAG in terms of attractiveness and cultural radiance. The program "Une saison dans les étoiles" (2018-9) prefigures the type of events that the science center will offer, notably the exhibit "Les Mondes Inconnus" that invites visitors to explore the Univers by solving puzzles (three sites: Casemate, Muséum and OSUG).
- Computing services are also increasingly mutualised to avoid duplicating tools and expertise in OSUG labs: two computing engineers formerly at IPAG are now under OSUG supervision, one fixed-term technician hired by OSUG works for both ISTerre and IPAG. Recently, OSUG has obtained a permanent position for these functions. OSUG also interfaces with **GRICAD**, the local tier-2 computing facility that includes data storage (SUMMER) and HPC (Ciment) services, with OSUG and IPAG staff involved in the running of this key facility for our scientists.

Third, OSUG manages the **Labex OSUG@2020** that supports projects on observation, data reduction, data bases and computing (9 ME, 2011-9). This encourages our links with other OSUG laboratories (e.g. with ISTerre on Martian studies, IGE on atmospheres) and the development of shared analysis facilities. IPAG received about 0.6 ME from OSUG@2020 from 2014 to 2018 (excluding PhDs). Highlights from this funding are the support for the R&D projects HDC (high contrast + VIPA spectrometer) and Aerocarb (a SPOC on a drone prefiguring NanoCARB), the development of CTA and Spirou, support for observations with SPHERE, PIONIER, GRAVITY, ALMA, NOEMA, for laboratory equipment (spectrogoniometer), for the Planeterella, for organising school, workshops and conferences. The Labex also provided full support for 1 PhD, partial support (1/2, 1/4) for two other PhDs and a useful "welcome grant" of 3 kE to newly-recruited researchers. OSUG@2020 has been renewed for the period 2020-2025 with a focus on "habitability". One of its four axes, pushed by IPAG scientists and management, is "what makes and keeps planets habitable?". Although this theme is transverse to IPAG, a concern is that it de facto excludes many excellent research lines being pursued at IPAG.

IPAG is the lead institute for the **Labex FOCUS**, jointly with CEA/AIM. FOCUS aims at developing high technology detector arrays of sensors to equip the next generation facilities for universe sciences. FOCUS has a national role in structuring this effort with 9 labs involved, including 6 in the Grenoble area (9.5 ME, 2011-9). The Labex is an enormous boost to our instrumental research. For IPAG, it has supported the development of the arrays of KID detectors for NIKA2, provided the new generation RAPID detector for PIONIER, developed prototype compact integrated spectrometers (Swift, SPOC) that have attracted additional funding (FUI IMAGAZ with SOFRADIR, FUI ImSPOC-UV with Pyxalis and Total, H2020 SCARBO with Airbus), and will be placed onboard the ATISE nanosat (see below). SInce 2014, FOCUS has provided support for these actions to IPAG in the form of 2 PhDs, 3 postdocs, 2 apprenticeships, equipment, for a total of about 0.8 ME. Our physics M2 students also attend the one-week detector school organised by FOCUS at the OHP, with strong involvement from IPAG staff and scientists. We have excellent feedback on this school, which trains 40 students every year from various universities in France. FOCUS has been renewed until 2025 around scientific objectives matching those of IPAG.

IPAG scientists have played a key role in creating the **Centre Spatial Universitaire Grenoblois** (CSUG). The CSUG was inaugurated in 2015 to develop fast track access to space through cubesats, to promote space applications for local technologies, to train students (~120/year). Its offices are located next to ours in Phitem D. CSUG has been very successful in forming partnerships with industry (Air Liquide, EDF, SOFRADIR, etc). IPAG scientists, engineers, technicians are involved in several CSUG projects: AMICAL Sat (2U, launch summer 2019), an imager for the 3D mapping of the auroral oval, ATISE (12U, launch 2021), carrying a compact spectrometer to study emissions from the upper atmosphere. The ATISE spectrometer is based on FOCUS developments, as is the spectro-imaging SPOC concept that led to the NanoCARB (SCARBO) project. This is another 12U cubesat project involving IPAG scientists, targeting daily monitoring of greenhouse gas concentration on the Earth surface. The latest project is an Auroral monitoring microsat for ESA's Distributed Space weather Sensor System (D3S, 2023-6). IPAG contributes significant amounts of manpower to CSUG, causing confusion within the lab as CSUG now expands into scientific territory beyond ours. Our policy is to anchor these CSUG activities within OSUG, its natural (and official) academic partner.

In the past years, we have formalised scientific ties with other local research units. We have several conventions between Univ. Grenoble Alpes and **IRAM**, situated next door to us, to clarify our relationships in terms of research, training, and personnel. The last Hcéres committee recommended that "*links with IRAM (...) must be much more developed*". A visible consequence is that one IPAG CNAP astronomer is currently detached at IRAM. The IRAM facilities are widely used by IPAG scientists in the Interstellar and Odyssey teams, with frequent interactions on data analysis and IPAG astronomers providing services to IRAM. Our seminars are organised jointly with IRAM. The Labex FOCUS, of which IRAM is also part, has helped deepen collaborations: on the NIKA2 camera for the 30m, on M2 students training on the 30m dish. In coordination with CNRS and Univ. Grenoble Alpes, we are now in the process of establishing with the Institut Néel, IRAM, LPSC, a "**Groupement d'intérêt scientifique**" (GIS) on the conception and development of KIDS detectors. The GIS builds on the advance of the group on this technology and the strength of its long-standing collaboration on submm detectors (Planck, NIKA2).

Within **Univ. Grenoble Alpes**, IPAG is one of the 15 research units that compose the Pôle de Recherche "**Physique des particules, Astrophysique, Géosciences, Environnement et écologie**" (PAGE). This is one of the 6 poles through which the university deploys its research policy, including elements of its IDEX project to make it an international research university. IPAG management and (elected) scientists actively participate in its board meetings. IPAG has an important role as it is at the junction of the "universe: birth, composition, evolution" and "planetary systems and planet Earth" research axis identified by PAGE for the next five years. PAGE provides advice to the University on its research strategy, including prioritising permanent staff recruitment. It also manages a few calls for projects. The "Initiative de Recherche Stratégique" (IRS, previously AGIR) is relatively open, hence heavily oversubscribed. It typically distributes ~140 kE and funding for ~4 PhD thesis per year amongst the >500 scientists of the pole PAGE. From 2015 to 2019, PAGE financed 8 IPAG

projects, out of 34 submitted IPAG proposals, for a total of 484 kE. The "International Strategic Partnership" (ISP) targets joint PhDs with specific partner Universities who must provide half the funding. IPAG was awarded funding for two PhDs over the past 3 years, out of ~23 projects/year for the whole Univ. Grenoble Alpes. The full list of IPAG projects funded by PAGE is given in Part I-9 - Academic research grants. PAGE also reviews applications from its professors for research sabbaticals: IPAG scientists typically get 1 to 2 semesters per year of "CRCT" out of the local or national (CNU) allotments; IPAG scientists also got 8 semesters of delegation to CNRS out of the 20 allocated to PAGE in 2017-9. Last, PAGE reviews applications for visiting professorships: IPAG got 17 months out of a total of 85 months attributed in the past three years.

The main benefit to IPAG of the IDEX awarded to Univ. Grenoble Alpes level has been the selection of the **Cross-Disciplinary Program** "Origin of Life" in 2017. This is an interdisciplinary project led by IPAG involving 8 other UGA laboratories. It has a budget of about 1.5 ME that allows it to hire several postdocs and PhD students. IPAG hosts four postdocs, including one in partnership with the ERC DOC, and 1,5 PhD student out of a total of 7 postdocs and 4 PhDs. The 4 postdocs and 1,5 PhD at IPAG are in three different scientific teams, and in strong collaboration with a fourth one. Importantly, the CDP has a very active program of scientific animation to bring together scientists with very different backgrounds, e.g. biology (Cell and Plant Physiology Laboratory and IBS), chemistry (IBS and DCM); environmental science (LECA), information and communications science (GRESEC), who are new partners for us at IPAG. IPAG is also a partner of the CDP "Data Institute", which has funded a postdoctoral chair. The IDEX has selected 17 such CDPs. The IDEX funding remains with the central services of Univ. Grenoble Alpes so the CDP does not contribute to our budget.

Locally, IPAG benefits from the central services of the CNRS local representation ("**délégation régionale**" DR11) and those of **Univ. Grenoble Alpes**. Close relationships with their services are indispensable for contracts and human resources. DR11 has provided very important external coaching assistance to IPAG in several instances. Our recruitments have strongly benefited from expert help provided by Univ. Grenoble Alpes. CNRS DR11 and Univ. Grenoble Alpes are very attentive to fostering ERC projects, providing expert reviews of projects prior to submission. Both now take an overhead of 15% on all projects, up from 8% prior to 2018. We worry that this will impact the amount of overhead we can levy for our common budget. We also worry that more and more large-scale projects will be directly handled by central services, like the CDP Origin of Life already is. This may have advantages but it also means that no overhead is available to support the project's implementation at IPAG. The CNRS DR11 redistributes 4% (out of its 15% levy) to the lab hosting the project. Univ. Grenoble Alpes keeps all the overhead in support of its research strategy. IPAG scientists, in coordination with the management, have thus directly solicited and obtained major financial support for CFHT/Spirou (2013) and the high contrast mode of ELT/HARMONI (2019) from Univ. Grenoble Alpes.

Finally, we note that the **Auvergne Rhone Alpes** region is absent from our local research ecosystem. Its support, focused on innovation in technology with a high economic return for local companies, is ill-suited to our needs. This contrasts with the situation in other labs in France where the region takes an interest in basic research, most prominently the Ile-de-France region.

3- Research products and activities for the unit

Scientific track record

Publications in peer-reviewed journals are the major product of our research. We've published more than 1300 papers in refereed journals over this evaluation period, compared to 1068 in the previous one. This represents an increase of about 5% per year, probably comparable to the overall growth in our field (4% from 1975-1995, see here). About 140 publications (11%) involve more than one team, more than twice the number (52) in our previous report. About 13% of the publications involve our graduate students. Our first author papers represent 17% of the total, with variations from 13% (Interstellaire) to 33% (Cristal). Most of our papers are in Astronomy & Astrophysics, followed by Astrophysical Journal and Monthly Notices of the RAS. The Planéto team publishes in a wider variety of journals. We co-authored 22 articles in Nature and 11 in Science, compared to 6 and 10 (respectively) in the previous report. This increase is largely due to the many results coming from Rosetta. Nearly all publications are in open access on ArXiv.

Nearly all our publications involve external authors. IPAG scientists are members of **international collaborations** built around major facilities Sphere, Pionier, Gravity, NIKA2, HESS, Fermi-LAT, Gaia, Sophie, Spirou, Harps, Alma, NOEMA, Planck, Herschel, Rosetta, New Horizons, Mars Express, MRO, Hayabusa-2 or in the future MAORY, HARMONI, CTA, SVOM, NIRPS, Concerto, Juice, Europa Clipper, Mars2020, ExoMars, Plato. We have long-standing collaborations with scientists at Caltech/JPL, University of Michigan, Universities in Geneva, Rome, Torino, Madrid, Heidelberg, Bremen, Dresden, Montréal, Santiago de Chile, Rio de Janeiro, Melbourne, Tokyo, Wuhan, etc. Our research is integrated in European networks: the ITN ACO, the Discanalysis and StarFormMapper teams, the Europlanet2020 and Opticon infrastructures. We also lead or join nation-wide

research projects: over the evaluation period, we have led 17 ANR-funded projects, including 9 ANR « blanches » and 3 ANR « jeunes chercheurs », and participated in 8 other ANR projects with other French labs. The Univ. Grenoble Alpes cross-disciplinary project « origin of life », the CNRS 80PRIME project « EXploring Planet formation with lab ExpeRimenTS » prove that **interdisciplinary** research is also explored at IPAG.

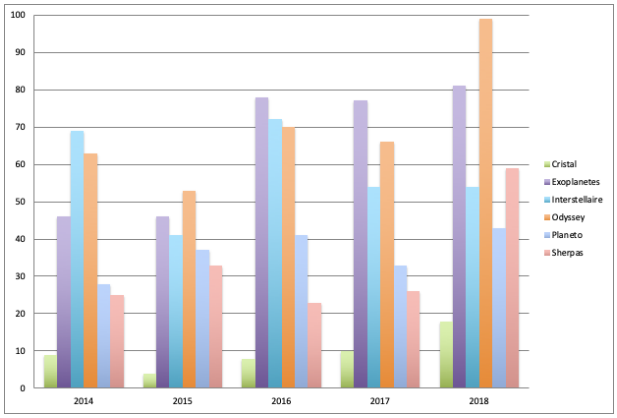


Figure : *Publications in peer-reviewed journals per team and per year. The total in the table is for unique articles (the sum of all team articles is greater because of multi-team articles).*

In the planetary sciences, **laboratory** measurements of extraterrestrial matter or analogues bring in data that complements in situ or remote observations. We have designed or acquired new cutting-edge equipment for our labs to keep us competitive (see highlights). Our measurements of various samples feed the European interoperable Solid Spectroscopy database infrastructure (SSHADE), opened in early 2018. We provide these data and other high value tools in the framework of our INSU **observation services**, notably for high-contrast observations (SPHERE-DC) and optical interferometry: we host the national Centre Jean-Marie Mariotti for IR/optical interferometry (JMMC). We have recently added Gaia to our observation services, with a focus on identifying binaries that fits with our objectives in exoplanetary science. MAORY is now also identified jointly with MICADO as a service, preparing for the future. We also provide access to **software** developed at IPAG, in particular MCFOST, a Monte Carlo code for radiative transfer in protoplanetary discs that is indispensable for the analysis of SPHERE and ALMA images, and ZELTRON, a Particle-In-Cell code that is unique for being adapted to high-energy astrophysics (Fermi, CTA) and publicly available. ZELTRON has been used for the first global simulations of pulsar and black hole magnetospheres (PRACE allocation of 27 million CPU-hours).

The **major instrumentation projects** we have brought to fruition in the past years are Sphere, NAOMI, Gravity for ESO. We've led the operations of the CONSERT instrument for Rosetta and PHILAE. We've built an innovative three-telescope observatory at La Silla for the ERC project ExTrA to search for exoplanets around M dwarfs (see highlights). We've participated in the assembly and tests of NIKA2 a mm camera for the IRAM 30m telescope, delivered and commissionned between 2015-2018. We've consolidated our involvement in ELT first light instruments: we contribute to the AO wavefront sensors of MAORY and HARMONI, a high-contrast mode to the latter, and detector expertise for MICADO. The massive implication of many IPAG people in these projects, now and for the coming years, was decided after a careful one-year study done by an ad-hoc in-house panel and approved by the laboratory council in 2018. Subsequently, UGA has accepted to fund partly the HARMONI high-contrast arm, giving IPAG a visible position, with LAM, in the HARMONI consortium. In addition to these projects, we are responsible for the 80,000 light concentrators of the CTA NectarCAM cameras, whose construction is officially funded as a national research infrastructure (TGIR) since 2018. We develop the next generation of radars for the tomography of Solar system small bodies. We contribute to the nanosats ATISE and AMICAL Sat to be launched by CSUG.

We have carried out several **R&D projects**. We've explored radar concepts for ESA (AIDA, MASCOT, UWBT). Petit Cru to measure polarised auroral emission was tested at Svalbard and is now followed by a prototype, Grand Cru, that will measure in 4 bands simultaneously for space weather applications. HDC is a bench to demonstrate the combined use of high contrast and high spectral resolution with a VIPA. NEAT was to demonstrate high precision astrometry for a space mission. The SPOC (SPectrometer On Chip, patented by Univ. Grenoble Alpes and ONERA) concept has taken off with multiple projects funded for various applications: Aerocarb (OSUG@2020) placed one on a drone, IMAGAZ (FUI) demonstrates the measurement of toxic emissions in industrial infrastructures (with Total), ImSPOC-UV (FUI) extends the concept to visible UV for space weather and upper atmosphere chemistrys, SCARBO (H2020) aims for a flotilla of nanosats to measure greenhouse gas concentrations (with Airbus).

Key events

We highlight here some key IPAG activities and their evolution over the past 5 years. These were chosen because of their impact on the life of the institute, because they involve staff all across IPAG, because they showcase long-term investments, because they have a large echo with non-specialists. A number of other major results or events to complement this list are highlighted by the scientific teams.

IPAG moves from OSUG-B to D

A key event in the life of the institute was the choice made in the spring of 2015 of moving out of the OSUG-B (CERMO) building in favour of the 2nd and 3rd floors of the newly built OSUG-D building. At the same time, the OSUG management was moving out of OSUG-A to the 1st floor of OSUG-D, liberating all of OSUG-A for IPAG. A special committee smoothly planned and managed in record time a complex operation that involved 77 people moving, re-installing laboratory equipment, setting up security, entrance badges etc. The whole operation was officially wrapped up in December 2015.

Rosetta reaches Chury

The beginning of the period under review was marked by the arrival after a journey of 10 years of the Rosetta space probe to comet 67P/Churyumov–Gerasimenko, with orbital insertion in August and the landing of Philae on November 12, 2014. The Planéto team was heavily involved in this mission, notably through the development and/or scientific exploitation of the CONSERT, VIRTIS and COSIMA instruments. CONSERT uses variations in the propagation time and amplitude of the radio waves exchanged between probe and lander to study the internal structure of the nucleus. It was built and operated by a consortium led by IPAG. The year 2014 was intense as the instrument was controlled by the IPAG team. CONSERT showed the smallest of the two lobes of 67P to be homogeneous on scales of a few meters, with a high porosity, and we deduced from the electrical properties that its refractory fraction is composed of at least 75% of organics (volume ratio). CONSERT distance measurements were used to narrow down the search region for Philae after its eventful landing, adding to the high visibility of the team. VIRTIS is a visible-IR imaging spectrometer designed to measure variations in the surface composition and temperature. IPAG participated to the instrument specifications and provided laboratory measurements of surface properties in support of the observations. VIRTIS found evidence for a water cycle on 67P, with ice periodically appearing and disappearing due to changes in Solar illumination. IPAG also participated in the studies performed by COSIMA, an instrument that performed onboard mass spectrometry on sub-mm particles captured around the nucleus. COSIMA found that these particles are made of nearly 50% organic matter in mass. The overall composition, rich in carbon and non-hydrated minerals, confirms 67P is made of primitive material preserved since the formation of the Solar system. Rosetta was officially ended by ESA in September 2016. The public response to Rosetta has been enormous. The Planéto team has been strongly solicited to explain the results, with dozens of interviews, interventions or lectures. One highlight was the remote participation from ESOC of two IPAG scientists in the live broadcast of the PHILAE landing at the Cité de la Vilette, with the French president attending. This was also broadcast live at the Grenoble town hall.

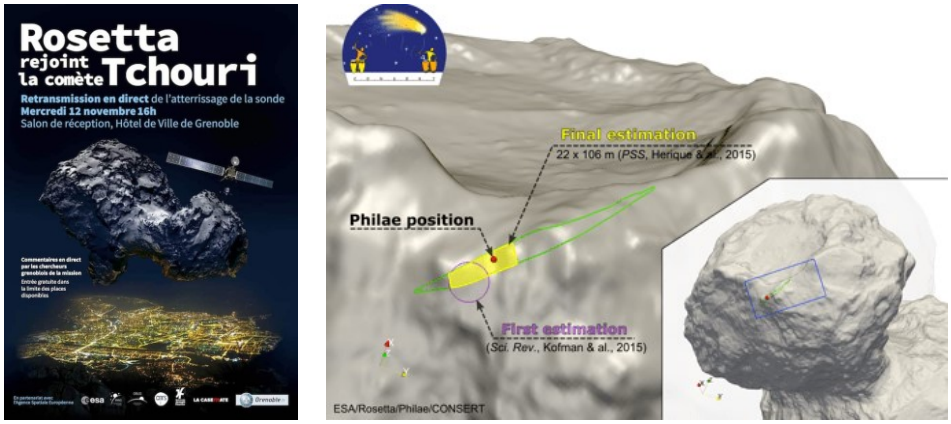


Figure : *Philae landing public event in Grenoble. CONSERT constrains its landing position on Chury.*

Optical interferometry comes of age

The past five years have seen spectacular advances in optical interferometry, a coming of age for a technique with a long history at IPAG. The integrated optics chip at the heart of the PIONIER and GRAVITY instruments are the fruit of a nearly 20 year long close collaboration between scientists at CEA-Leti and IPAG to adapt telecoms technology for use in astronomy. These chips have enabled stable and accurate recombination of the light from the 4 telescopes of the VLTI. PIONIER, developed by an IPAG-led French consortium, was the first instrument to achieve this. In June 2015 a new infrared camera, RAPID, was installed on PIONIER. This camera is the product of 5 years of collaboration between SOFRADIR, IPAG and academic partners (FUI RAPID). This has led to a flurry of scientific achievements including the first image of hot circumbinary dust in a post-AGB binary, resolving the disks of Herbig AeBe stars on AU scales, an image of convective cells at the surface of a red giant. GRAVITY benefits from this accumulated experience. GRAVITY saw first light in November 2015. IPAG scientists were amongst the first to publish scientific results with it, showing that the optical emission from the relativistic jets of SS 433 originates closer to the compact object, most likely a black hole, than expected. In 2018, the GRAVITY consortium achieved its design objective when it measured general relativistic effects on the orbit of the star S2 at the time of its closest passage to the Galactic Center black hole Sgr A*, and provided us with the spectacular observation that infrared flaring is associated with a hot spot rotating close to the last stable orbit of Sgr A*. The latest exciting result is the extraction of the spectrum of an exoplanet with unprecedented quality. The high angular resolution enables to filter out the stellar light, demonstrating a promising new approach to characterise exoplanets. GRAVITY lead to 6 ESO press releases and one ESO press conference involving an IPAG scientist. Finally, IPAG delivered NAOMI, an adaptive optics system for the auxiliary telescopes of the VLTI developed in collaboration with ESO. NAOMI greatly enhances the performance of the VLTI when the ATs feed PIONIER, GRAVITY or MATISSE. NAOMI was one of the major instrumental developments carried out by IPAG over this contractual period, with a first IPAG proposal to ESO submitted at the end of 2013 and preliminary acceptance in Chile in March 2019.

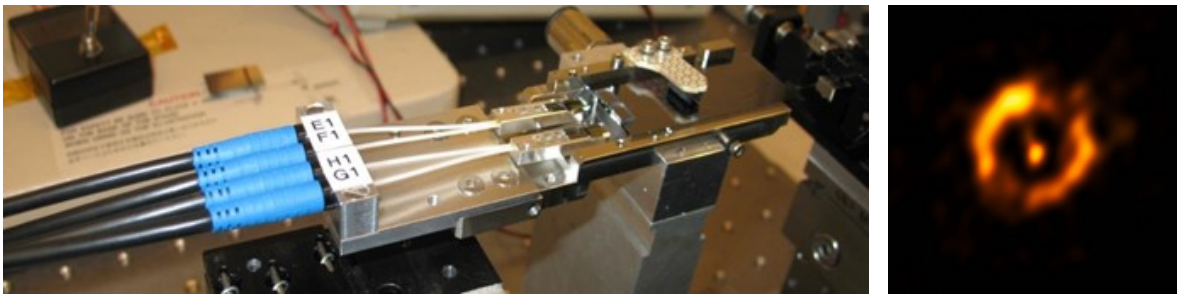
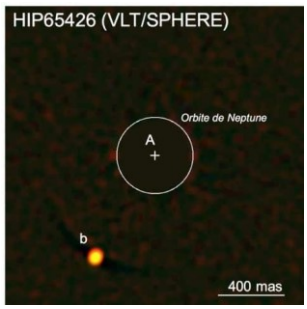


Figure : *Integrated optics component made at IPAG for GRAVITY. Reconstructed image of the dusty disc around an aging star using VLTI/PIONIER.*

SPHERE: a new view of planet formation

SPHERE, a VLT instrument designed for high contrast imaging of stellar environments to search for planets, was shipped to ESO in 2014 after a 10-year development by an IPAG-led international consortium. SPHERE represents a huge investment from IPAG. Its scientific exploitation has been a priority of the current contractual period. The instrument was installed on UT3 in May 2014. SPHERE has achieved the high performances that were targeted. SPHERE reported its first detection of an exoplanet in 2017 and the first direct detection of a young protoplanet within a gap of a transition disk in 2018. A stunning timelapse of the exoplanet Beta Pic b was made in 2018 combining 8 years of data from NACO and SPHERE, which both had PIs from IPAG, testifying to the long engagement of the institute in direct imaging. Yet, exoplanets have proven more elusive than expected, placing constraints on their population in a previously poorly-known region of the orbital distance - period diagram. However, the instrument has provided a string of spectacular images of disks, especially around young stellar objects, starting with the discovery of moving wave structures in the debris disk of AU Mic. The variety of observed protoplanetary disk structures is baffling: the theoretical challenge is being taken up by the ERC MHDiscs. Together with ALMA images, SPHERE images have driven the field of protoplanetary disks forward, with major international impact. The SPHERE GTO consortium has released 75 papers in refereed journals so far (15 were led by IPAG PI's, and 7 more featured IPAG as senior author, in second place immediately behind a PhD candidate from another institution). Another 25 were published as part of the early science verification call by ESO, testifying of the attractiveness of the instrument, from the very beginning. The pressure factor on UT3 has been >3.5 steadily over the last semesters.

Figure: *SPHERE in the IPAG integration hall* (left) *and at UT3 in Chile* (right).



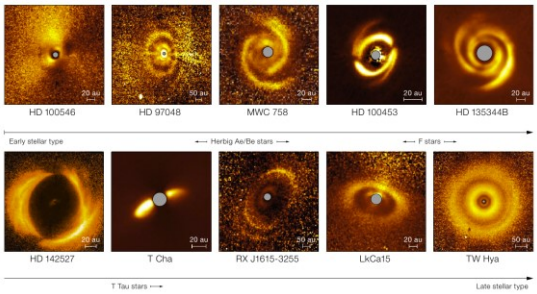


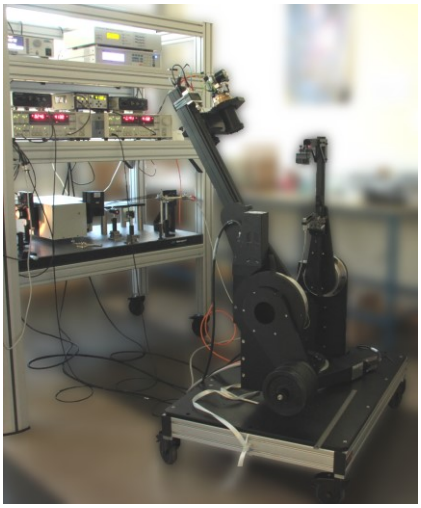
Figure: First new exoplanet detected by Sphere (left) and the variety of protoplanetary disks observed by SPHERE (right).

ExTrA information on exoplanets

Figure : *The ExTrA observatory at La Silla.*

Besides SPHERE, the last 5 years have confirmed IPAG as a main actor in the field of exoplanetary studies, notably through a strong collaboration with people at the nearby Geneva Observatory to exploit radial velocity programs using HARPS at La Silla or SOPHIE at the OHP. These are very fruitful, with a string of discoveries reported in press releases: planets in the temperate zone around a red dwarf star, including a super Earth, susceptible to future characterisation by the ELT, a planet whose orbit is misaligned with the spin of its star. Other techniques have led to intriguing results: ALMA observations have led to the indirect detection of an exoplanet being formed, through its dynamical signature on the circumstellar disc, while spectropolarimetric observations with ESPaDOnS and Narval uncovered a hot jupiter close to its very young parent star, indicating it must have formed very early on. The question of star-planet interactions is being further advanced through the ERC SPIDI. A major effort at IPAG over the past 5 years has been the construction of the ExTrA observatory at la Silla. ExTrA uses an innovative approach to obtain high-precision (milli-mag) near IR photometry, with fibers bringing the light from three 0.6m telescopes to a multiobject spectrograph. The goal is to survey a large sample of target stars for planetary transits to constrain their parameters and population statistics. A major by-product is that ExTrA will pinpoint the most interesting systems for spectroscopic characterisation of their atmospheres with the ELT. ExTrA, funded by an ERC, is developed exclusively by IPAG. The project has challenged IPAG, the observatory seeing first light in early 2018 with routine observations due to start soon.

Shining light on SHADOWS and our laboratories



Our planetary sciences laboratories have seen major upgrades in equipment to keep them at the forefront. Building on SHINE, we have developed a new spectro-gonio radiometer, SHADOWS, for accurate measurements of the bidirectional reflectance of very dark and precious samples (meteorites or analogues measuring less than a 1 mm^3 and reflecting less than 0.03% of the light). The instrument operates over almost the whole solar spectrum and is installed in a room that can be cooled down to −20°C. The illumination and observation angles can be varied over a wide range. These measurements feed the GhoSST database, now incorporated in the newly opened SSHADE European database. The facility is open to outside users through the Europlanet 2020 research infrastructure. Another highlight is that we refurbished a laboratory (air conditioning, nitrogen distributor, etc), with help from UGA, to host the new equipment in support of the ERC SOLARYS: an atomic force microscope, an isotopic ratio mass spectrometer. Thanks to INSU and UGA we have also improved access to the integration hall to help host large instruments.

Figure : *The SHADOWS spectro-goniometer at IPAG.*

4- Organisation and life of the unit

Steering, life, organisation in the unit

Steering and organisation

The director of IPAG elaborates and carries out the scientific project of IPAG. He manages the resources available to the research unit in coordination with Univ. Grenoble Alpes and CNRS, with help from his management team. The management team is composed of the director, the deputy director, the technical director and the administrator. The team meets once a week for a "**comité de direction opérationnelle**". The overall organisation and regulations in place at IPAG are detailed in an internal document ("**règlement intérieur**") that has been formally approved by CNRS, UGA, and our lab council (see below) for the 2016-2020 period. This document is available on our intranet.

IPAG research is organised around the **scientific teams** that consist of permanent researchers, research engineers, postdocs, PhDs, as listed in the organisational chart. Scientific teams have a representative, the "team leader", chosen by consensus. Team leaders participate in the management of the lab through the "**comité de direction élargie"**, which convenes every two weeks to discuss steering decisions. They are expected to relay information to and from the management team. They participate in the reviews organised by CAMPI (see below) on projects concerning their team. They are able to follow the financial resources available to their team. Pooling of resources is encouraged as a means to promote shared objectives. Teams cover the stipend of interns and any extension to PhD theses. Nearly all of the team funding is project-based, either from the programmes nationaux or from calls by CNES, the ANR, UGA, Europe. Depending on the status of our finances, from 3 to 5 kE/year/team is attributed from the IPAG common budget. Each team has an assigned "gestionnaire" from the administrative service.

Management of the **support group** is organised through monthly meetings between the heads of services and the technical director, assisted by other members of the management team as appropriate ("**réunion des responsables de service**"). The heads of services are consulted on matters related to technical and administrative staff at IPAG, notably on the allocation of ITA support to IPAG projects and on the yearly priorities for ITA recruitment sent to CNRS and UGA ("demande DIALOG"). A monthly project meeting is also organised to monitor progress on ongoing instrumental projects ("**réunion projets**"). The services are allocated a yearly budget for their internal seminars and other internal activities. A specific commission is set up for ITA career advancement, meeting 3 times per year ("**commission avancement**"). The role of this commission is to provide advice to the director on ranking the career advancement propositions made by the heads of services. The commission is composed of the director, the technical director, the administrative head, the heads of services and two ITA representatives of the lab council (see below) who act as observers.

The **"Conseil de Laboratoire**" (CdL, laboratory council) is a statutory body presided by the director. The council provides advice on all matters relating to scientific orientations, lab resources and budget, its organisation and operation. The lab council convenes every 2 to 3 months. The minutes of its meetings are accessible to IPAG staff on our intranet. The composition of the council (director and his deputy, 12 elected members and 6 members nominated by the director) and its bylaws follow CNRS regulations. The last Hcéres committee was surprised that "*team leaders are not systematically invited to attend (CdL) meetings*". The council declined to follow this recommendation as the "comité de direction élargie" now effectively involves team leaders in "*all management aspects*" compared to our previous organisation. The council is renewed every 5 years at the start of the new contract phase. Elections to the laboratory council are organised by the electoral commission ("**commission électorale**").

The "**Commission Hygiène Sécurité Condition de Travail**" (CHSCT, hygiene, security, work conditions) is another statutory body of the lab that deals with all occupational health and security issues that may arise in the lab. The meetings are conducted by the two IPAG staff with specific training in risk prevention. The commission also includes the director and 7 representatives of the laboratory. It meets at least once a year. Health & Safety is further discussed below.

The "**Groupe d'Aide aux Doctorants**" (GAD) is a group of 6 permanent scientists from different teams who meet all PhD students individually at least once every year for ~20mn confidential interviews. Their role is to provide an external view of progress towards PhD completion, to make sure students have the appropriate environment to carry out their research, and to help mediate as needed (and requested). The GAD is not asked for scientific feedback on the PhD. After each interview, the GAD sends a brief report for approval to the student and the supervisor, and for information to the director. The interviews typically lead the GAD to provide follow-up mentoring to 3-4 students/year. In addition, to help students with their professional future, the GAD organises meetings for current PhD students with former students working in the private sector and with IPAG scientists who have participated in recruitment committees for CNRS, CNAP and Universities.

The "**Cellule d'Aide au Montage de Projets à l'IPAG**" (CAMPI) was created in 2013 to provide a framework for new projects at IPAG. All new projects with substantial budgets (>100 kE) and/or requesting substantial technical or administrative resources from the lab are systematically reviewed by CAMPI. Help from CAMPI can also be solicited on demand. The goal of the review is to provide advice to the project coordinator, the review being a good testing ground for the project's scientific, technical and administrative aspects, and to discuss its integration within IPAG to ensure a successful implementation. CAMPI clarifies with the coordinator what level of support to expect from IPAG and the amount of overhead levied by the lab. CAMPI also reviews projects after their acceptance to help the coordinator, or prepare arbitration by management, when evolutions in the project and its impact on the lab require it. CAMPI meetings are convened by the deputy director after an exchange with the project coordinator. Meetings typically involve the management team, the leader of the scientific team of the coordinator, heads of services and any other personnel as seen fit by the deputy director and the project coordinator. CAMPI meeting minutes and conclusions are prepared by the deputy director, shared for comment with the participants and archived on the intranet for future reference. CAMPI meets about 15 times per year.

CAMPI was one of the first steps taken up to set up a quality process at IPAG. Setting up a quality approach to the various processes at work in the lab has been discussed in the past years as a means to effectively handle their increased complexity. The computing service has strongly supported developing this quality approach and puts it in practice internally, most recently to keep a check on delays when providing a computer to new IPAG staff. A "**cellule qualité**" (quality group) was set up to implement this more widely. The group initially included representatives from scientific teams and support services. One practical outcome was an overhaul of our internal communication tools, with a change of our intranet to Confluence (see below). Together with the cellule qualité, the service informatique and the service gestion administration, IPAG management is implementing the quality approach on the buying process ("gestion et suivi des achats"). In parallel, CNRS/INSU is helping the lab by providing long-term professional expertise on quality to train IPAG staff, notably the management team, and to advise on the implementation of the quality approach at the institute. The "cellule qualité" now operates with a more compact group of 4 people, including the director, who are tasked with examining how the lab operates. The group solicits additional staff as needed. Further processes are currently being identified for our next action. A goal of our next contract is to see wider understanding, acceptance, and implementation of the quality approach at IPAG.

Life in the Unit

Internal communication

Our main tool for internal communication is the platform **Confluence.** It was proposed by the members of the quality group after a detailed study of the collaborative tools available on the market and then validated by

the laboratory council. It is organised in spaces (for people, teams, groups, projects) whose access can be open or restricted as necessary. Confluence allows forms, meeting minutes, collaborative writing, comments, archiving documentation (pdfs, charts, tables), traceability of action items, etc. Our report was elaborated with Confluence. Our intranet detailing all aspects of life at IPAG (travel procedure, library, equipment request, etc.) is on Confluence, with nearly all its pages translated to English. Each page has a contact point tasked with updating it. Feedback on Confluence has been very positive. Indeed, the platform is now also used by IPAG-led large scientific projects involving outside collaborators (e.g. the ITN ACO), a benefit to the lab's external visibility.

Ipag-news is a weekly email compiling all informations and news items collected by management for diffusion to the whole lab (messages from CNRS or Univ. Grenoble Alpes, seminar, events, press releases, call for projects, open positions, etc). The **CRI** is our weekly pre-seminar coffee on thursdays where all the lab is convened, irregularly used to introduce new staff to the lab. The whole lab is also convened at least once a year for an "**assemblée générale**" (general assembly). The management team recaps recent events and current issues for the lab personnel, followed by an open session for discussion and questions.

All lab members are also invited to the Lab days ("**journées du laboratoire**") organised every 2-3 years. They take place over three days and two nights, away from the lab. They are usually attended by 80-90 people. We had Lab days in March 2014 (Annecy), May 2017 (Autrans) and in April 2019 (Annecy). Their goal is to provide a global view of ongoing activities and future directions at IPAG, to discuss our organisation, to develop cohesiveness. The April 2019 days were focused on preparing this Hcéres report e.g. with team leaders asked to present their team as if we were in 2025. Half of the time was spent with attendees randomly assigned to different, small workshops to debate open questions ("what makes IPAG attractive?", "what evolutions will our jobs see in the next 5 years?", etc.). The resulting material was used to list possible action points for the lab council and the management team. All the material is accessible on Confluence.

The Lab days are also an integral part of our **scientific animation**. However, they must remain accessible to the whole lab. Specific sessions have been organised during the lab days or on other dates to allow in-depth discussions of more technical scientific aspects. For example, we've had a lab science day where authors of press releases in 2014 presented their work. There was also a Sphere day in 2015 with the morning devoted to presentations accessible to all and the afternoon dedicated to technical feedback on the project. We have a regular **PhD day** organised by the PhD students every Spring. The format evolves with the years but all students get a chance to advertise their work. The level of the talks usually targets the whole lab. The slides and program for all these events are on Confluence.

The **scientific team meetings** are at the heart of the scientific animation at IPAG. Teams are expected to have weekly meetings, to discuss scientific results, to encourage the sharing of ideas, to bring about new projects, to set their objectives and priorities. Teams have their own Confluence space to share slides, documents, calendars, etc. Scientific teams play a collective role in the formation of trainees and PhD students: team meetings are often the first place where their work will be exposed and discussed by specialists. The scientific teams are key to integrating new arrivals within the lab. Likewise, each **service** is expected to hold regular meetings, as recommended by the last Hcéres committee. Teams structure IPAG but should not be silos for people and ideas. Scientists can have a secondary affiliation to another team. In practice, this enables the person to be on the team mailing list, access its Confluence space etc. More generally, we need to work on a more systematic way of spreading information on team scientific life to facilitate participation from other scientists, regardless of their official team or service affiliation.

Finally, the **IPAG seminar** is a staple event of our scientific animation, held every Thursday except during school holidays. It is organised by two researchers in collaboration with IRAM, who collect suggestions for invitations every six months. IPAG covers travel expenses within Europe and a one-night stay. We've had 183 seminars from 1/1/2014 to 30/6/2029 on all subjects of interest to IPAG, and beyond (full list on website). They are well-attended, some seminars overflowing our room's capacity of 70 people.

Human resource policy

All new IPAG personnel (trainees included) go through a "new arrival" procedure, taking them to meet administration, computing, health & security, team or service leader, ending up with an interview with the director.

ITA and BIATSS personnel from the **support group** are under the responsibility of the director, who follows the HR regulations set by CNRS and Univ. Grenoble Alpes. CNRS has implemented over the course of this contract the possibility for the director to attribute bonuses to CNRS ITA at IPAG ("complément indémnitaire annuel", CIA). IPAG management has setup a grid-based evaluation considering yearly achievements and participation to

the life of the lab. The IPAG policy for promotions is discussed in the "commission d'avancement" (see above). Since 2014, we've had 13 grade promotions ("changement de grade"), 5 status change ("changement de corps"), 1 promotion to the upper grade of engineers ("IRHC"), 3 passages to the last level of IRHC ("HEB"). This impressive number of promotions in the last five years (CNRS, UGA) shows the quality, skills and performance of IPAG engineers and technicians at the national level.

We have been regularly recruiting on fixed-term contracts for ITA-level positions. We have strived to improve our recruitment procedure, with the goal to anticipate on their integration within the lab. We've received much appreciated help from the human resource department of Univ. Grenoble Alpes in conducting interviews and in discussing our long-term strategy. Because of our dearth of permanent ITA staff, we're being forced to consider open-ended contracts (CDI) to stabilise staff with critical expertise, something Univ. Grenoble Alpes is open to. In this context, we're keen to hire people with a high level of expertise and potential with the goal to anchor some of them at the lab on open-ended contracts after 4-5 years. Priorities for the recruitment of permanent ITA staff are set every year during the DIALOG phase with our supervising bodies. Our priorities result from a process involving the heads of services, scientific team leaders and IPAG management. The priorities are presented to the lab council and shared with the lab (our DIALOG submission is accessible to all on our intranet).

For **researchers**, IPAG does not set priorities on permanent CNRS and CNAP positions so long as the candidate's integration in the lab is well-established. Applications are reviewed and discussed by the "comité de direction élargie". IPAG has consistently been pushing Univ. Grenoble Alpes (UFR Phitem, pôle PAGE) for an associate professor position on "the origin of planets and conditions for their habitability", a profile that was repeatedly discussed in the "comité de direction élargie". We've also consistently pushed for promotion opportunities for our current associate professors. Our postdocs and PhD students are concerned by the lack of positions in academia. IPAG researchers, as elsewhere, help candidates improve their applications. We've organised panel discussions with former members of hiring committees so they can explain the process to postdocs and PhD students. We've also organised, at other times, panel discussions with former IPAG postdocs or PhDs who do not work in academia anymore. These events have been more irregular lately. PhD students are interviewed regularly by the GAD (see above) and we've recently set up yearly interviews of team leaders with postdocs as well, so that we have a feedback on their IPAG experience. Postdoc and PhD recruitment is left to scientists themselves with the provision that they must follow CNRS HS4R guidelines.

Teleworking is now possible for all CNRS personnel and for BIATSS Univ. Grenoble Alpes staff. Only Wednesdays and Fridays can be teleworked at IPAG, a decision that was taken after consulting team leaders, heads of services and the lab council. This possibility has been taken up by a couple of people only.

Our personnel have access to **training** courses through CNRS or UGA. We have two correspondents for training ("correspondants formation") who draw a yearly training plan ("plan de formation de l'unité"). Most of the courses concern expert training (software, etc), language courses (English), personal development or management courses come next.

We are attentive to our personnel with special needs or disabilities, in coordination with CNRS and UGA, for instance by adapting their workplace.

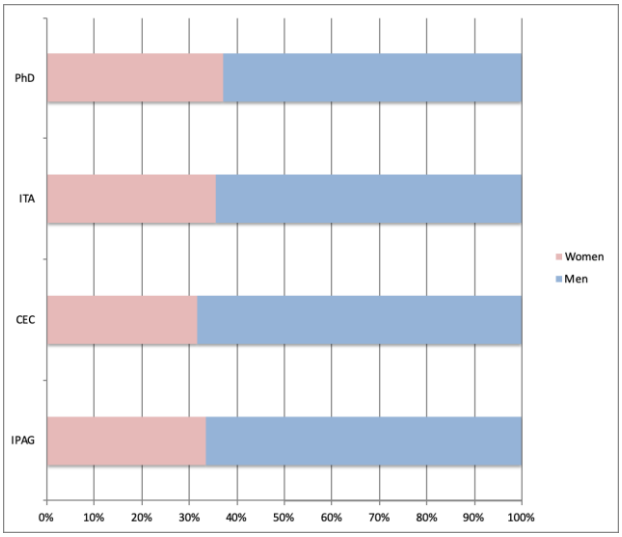
Allocation of resources

The majority of our resources come from project-driven funding. IPAG policy is to encourage team (or cross-team) efforts on projects and pooling of funding at the scientific team level. We've also seen teams pool resources to hire postdocs or PhDs. One recent difficulty has been the IRS call from the pôle PAGE, which requested labs to carry out a pre-selection to ease the pressure on their selection committee. We were asked to pre-select only 2-3 applications, something that stirred internal debate as to whether we should do this and what criterion to use.

Our common budget depends on the overhead we take on IPAG projects. We provide funding from the common budget for actions that benefit the whole lab: infrastructure, lab life, and, increasingly, hiring support staff on fixed-term contracts. We also provide some basic support to the scientific teams and to the support group. The common budget does not fund internships, nor does it fund extensions to PhDs or postdocs. These are expected to be the responsibility of the scientific teams.

Parity; scientific integrity; health and safety; sustainable development and environmental impacts; intellectual property and business intelligence.

Parity



Parity is clearly not reached at IPAG. Looking at our current IPAG staff, women represent 33% of the total staff, 33% of scientific team leaders (2/6), 39% of PhD students, 32% of postdocs, 30% of permanent researchers. This is better than the 23% found for CNRS researchers in astrophysics (section 17 in 2018). Things are stable since we have had two women hired out of the 6 researchers recruited at IPAG from 2014 to 2019. Parity was one of the items discussed in small workshops during the 2019 Lab Days. IPAG does not have a lab-specific policy on parity and this was not requested. The consensus was that parity needs to be considered when possible e.g. in the organisation of colloquiums, schools, in training. Late recruitment of new researchers is widely considered damaging to hiring women. Positive discrimination was said to arrive too late and lead to over-solicitation. Promoting scientific careers at earlier ages is thought more efficient. A possible action is to associate men and women scientists when visiting high schools.

Scientific integrity

We do not have a specific IPAG policy regarding scientific integrity. PhD students have compulsory training on this aspect through their doctoral schools. There are very different article signing practices within the lab, depending upon the project, collaboration, team, group, individual. IPAG is not different in this than any other international lab in astrophysics and space science. Several measures exist at the community level to detect plagiarism, with automatic cross-checks performed when submitting to ArXiv or to journals. We are fortunate to host the editor-in-chief of one of the main journals in astrophysics, who can provide advice should questions arise. A good practice, stressed by several during the Lab days in 2019, is to have people in a position of responsibility (PhD supervisors, project managers) clearly write down who does what. A specific point of attention is to maintain free sharing of ideas within teams. We see project-driven research as a potential threat to this open atmosphere. To avoid this, projects must be discussed within teams prior to submission to avoid misunderstandings. CAMPI meetings also emphasise project integration within the team and the lab.

Health & safety

IPAG has two prevention officers with 20% of their time officially allocated to this. They have a program of regular training updates. All new personnel is seen by one of our prevention officers as part of our "new arrival" procedure. Safety considerations are brought up as soon as possible when new instrumental projects are discussed. Contact points, procedures to access laboratory equipment, activities that require approval by a doctor, what to do in case of emergencies, etc, are all listed in the CHSCT space of our intranet and addressed by our internal regulations. The intranet also has the latest version of our risk evaluation document ("Document Unique d'Évaluation des Risques"), which is updated every year by the prevention officers and presented to the CHSCT. We have started collecting detailed documentation and regulations concerning laboratory equipment at a single location on the intranet, starting with an inventory of hazardous materials.

All IPAG personnel has access to occupational medecine through either CNRS or Univ. Grenoble Alpes. Regular training on preventive health and working conditions are proposed through UGA or CNRS. We prepare summary sheets on exposure to toxic products every year so that preventive medicine has better knowledge of which personnel require added attention. We have installed two defibrillators in OSUG A and OSUG D. Each building also has first aid medical supplies and a resting room. The chemistry lab is equipped with a shower, an eye-washer, two fume hoods. Hazardous products are stored in a dedicated ventilated cupboard in the chemistry lab. We have seen more widespread use of laboratory notebooks ("cahiers de laboratoires"). We perform periodic safety checks on all dangerous equipments (centrifuge, bridge crane, etc.), regularly training people on safety procedures. Trained people are listed in the internal regulations and on the intranet. Twenty people are up-to-date on their safety training (SST). Since 2018 we also have a laser safety officer. Regular fire drills are carried out with very good results. People assigned and trained to check evacuation in case of a fire alarm are identified on the intranet in a document that has their picture and a map of their assigned area. IPAG management regularly reminds personnel of the regulations concerning isolated work. The building is under alarm at night so this avoids late-nighters.

A web register SST hosted by UGA is available to personnel to point out problems relating to health & security. This register is checked periodically by the director and safety officers. The chemical register is also periodically updated. A procedure for the evacuation of chemicals is in place via a service provider. An issue is that UGA central services are not always responsive enough to solve security problems that have been identified together with their prevention officers e.g. removal of abandoned hazardous material, slippery surfaces...

Sustainable development and environmental impact

IPAG staff is highly concerned with the issues of sustainable development and environmental impact. Actually, there is a tradition of heated debates on our mailing lists on the best ways to mitigate mankind's environmental impact. Indeed, one of our researchers actually devotes the major fraction of his research time to sustainable development in collaboration with the team STEEP at INRIA. Several actions have been conducted at IPAG with mixed success, such as recycling bins or timers for lighting. Others have been proposed during our last Lab Days. Recycling of metallic material in the mechanical workshop is planned for next year. Most meeting rooms are now equipped with teleconferencing equipment, to help limit travels. We do have a shared car, available for use by the staff, with priority given to carpooling when going to meetings. Parking space is clearly decreasing around IPAG in connection with the construction of the "Maison Climat-Planète". Bicycle racks are available in our underground garage and surrounding our buildings. Univ. Grenoble Alpes is supportive of the installation of new bicycle racks. In terms of computing, we have a policy of pooling equipment in shared infrastructures to limit impact.

OSUG D is a new building with high environmental ratings but teething problems that should have been solved persist: windows in the bridge connecting to Phitem D are not up to the requested thermal standards, turning it into an oven during the summer; ventilation is very noisy and insufficiently well adjusted to maintain temperatures as it should; timers erratically turn lights on and off. A major difficulty is to find the right contacts who can take up responsibility and act on these issues. Similarly, OSUG A is a regular source of complains because of poorly adjusted heating during the winter and unbearable temperatures during the summer. We are currently investigating what we could do with UGA to improve the isolation of the building.

Intellectual property and business intelligence

Our head of the computing service is CSSI ("Correspondant Sécurité Système d'Information"), in charge of securing the IT services provided to IPAG. For example, our wiki system became obsolete for security reasons and has been completely renewed for this reason. We enforce encryption of all laptop and desktop computers. IPAG personnel are regularly reminded of this obligation. We closely monitor activities on our servers in order to prevent malicious activities.

We are sensitive to intellectual property issues. For example, there is currently one non-disclosure agreement in force. The entrance to IPAG is protected by a security system. Offices are protected by keypads. Our laboratories are protected by additional devices.

FIVE-YEAR PROJECT AND STRATEGY

We expect that the **major scientific drivers** at IPAG for the coming years will be

- the origin of carbon matter, pre-biotic molecules, molecular complexity, interstellar heritage;
- the initial mass function of stars, the dynamics and diversity of the ISM;
- the conditions for the formation and the signatures of planets in protoplanetary disks;
- the link between accretion, winds, and jets in disks around young stars and compact objects;
- the diversity of exoplanets, the origin of life;
- instrumental R&D towards these goals.

We believe that these themes are attractive, clearly identified as priorities on national and international roadmaps, and well-understood by our academic and non-academic partners.

Our first priority is to make full use of the **instruments that we contributed to develop**, whether they are on the ground, in space, or in our labs. "Flagship" instruments get major results, lead to collaborations, generate public interest, attract students and scientists. Currently, we have privileged access to cutting-edge instrumentation in operation like SPHERE, GRAVITY, NIKA2 and we have a track record of exploiting large programs on major infrastructures such as ALMA and NOEMA. The next years should see important additions to this portfolio. ExTrA, a major investment for IPAG, is to start routine scientific operations soon. ExTrA will realise its full potential in the next five years: following up on TESS results to fully characterise planetary systems, identifying the best targets for follow-up by the ELT. We will need to find ways to secure the operations of ExTrA (OSUG@2020, UGA, ERC). We will be strongly involved in the scientific exploitation of SPIRou, which has just started operations, in conjunction with upcoming data from Gaia (DR4), CHEOPS, JWST, NIRPS. Thanks to our expertise in KIDS, we are contributing to the CONCERTO instrument on APEX, which will open the door to astrochemistry and star formation at high redshift through observations of the CII line. In the planetary sciences, the next years will see us analyse asteroid samples returned by Hayabusa 2 and data collected with the rovers of ExoMars 2020 (ESA) and Mars 2020 (NASA), making full use of our laboratory facilities (Orbitrap, Low Mass spectrometer, micro-manipulation, AFM microscope, Shadows). On the high energy side, we will be involved in the construction of the NectarCAM cameras as CTA moves to full operations, and in the analysis of SVOM data. We will also have to prepare for the longer term, as detailed further below.

We need to find the **ressources** to fully exploit these scientific opportunities (computing, travel, PhDs, postdocs). ERCs and ANRs are a highly visible way to achieve this. We have 4 ERCs and 3 ANR "blanche" ongoing until 2023 that are boosting the modelling and experimental work required to interpret those new observations and address the themes listed above. Although these are highly competitive grants, we can reasonably aim to host, continuously, at least four ERC or ANR "blanche" projects as PI institute. We are also fortunate to be able to count on the support from two Labex (FOCUS and OSUG@2020) and the CDP "Origin of Life" in the coming years. They will help us to remain competitive for many – but not all – of our scientific goals. IPAG scientists are proactive but we are concerned that many calls for projects are increasingly targeted, towards themes with a large socio-economic impact or interdisciplinarity, making it difficult to find opportunities to support aspects of our core, basic science. The risk is a withering of theoretical studies, of long-term background work, or of highly exploratory science not attached to "flagships". Funding fluctuates widely, with greater amplitude than before between times of abundance and lean times, especially if ERCs and ANRs are the only options for some scientific groups. We try to dampen these effects by having teams pool resources in as much as possible. We also aim to maintain a healthy common budget to provide some basic support to our scientists. We worry that we may face difficulties in the future as rules or the amount of overhead taken by CNRS or UGA prevent us from levying projects. Long-term continuous support from CNES, CNRS and UGA remains absolutely critical.

Univ. Grenoble Alpes will evolve greatly in the coming years as it becomes an integrated university and as its IDEX funding enters its next phase. Key points of attention concern the long-term support and evolution for the Labex and CDP, the role and amount of support given to PAGE, possibilities for closer links with the Engineering Department (Grenoble INP). We will need to be present in the various structures set up by Univ. Grenoble Alpes to be attentive to the opportunities and threats. We are at risk of losing key expertise amongst engineers and associate professors for lack of positions and promotions at the University, a sore point of the last contract. This will have an impact on our presence in teaching and training University students, for whom astrophysics and the planetary sciences have great appeal. The next contract will see the metropolitan center for scientific culture open, materialising a long-term commitment of IPAG scientists to outreach. Explaining our research to the wider public is increasingly important. The communication team at OSUG is very active but needs more staff to be able to respond to the large demand that we see on science communication. IPAG also contributes a lot to showcasing the University via the CDP "Origin of Life", the space center CSUG, and the two

Labex. These bring resources but they also require permanent staff to run them and consolidate the advances they allowed. The University must help us with this.

Our projects are long term. Preparing for the period beyond 2025 will be a major part of our activity, with several instrumental projects due on this timescale. In particular, the **priorities for our technical group** will be

1. to achieve the design and construction of important parts of ELT first-light instruments: MAORY, HARMONI;
2. to take part in the design or construction of radars onboard planetary missions: RIME on JUICE (ESA), REASON on Europa Clipper (NASA), the proposed missions HERA (ESA), Chimera (NASA);
3. to achieve the R&D HDC on high contrast imaging and spectroscopy, helping us clarify future opportunities with HIRES and PCS on the ELT;
4. to achieve the R&D around miniature spectrographs and propose planetary science instruments based on those concepts.
5. to maintain and develop our current multi-technique facility to analyze primitive cosmomaterials and solar nebula solid analogs.

The current number of technical projects at IPAG is large compared to our dwindling support group. We need to keep the ability to conduct large "flagship" instrumental projects in the future. We must also find ways to contribute significantly to Efisoft, a national facility for ELT control-command commonalities that has recently been located at IPAG. **Strategic decisions** will have to be made on involving IPAG in upgrades to SPHERE or GRAVITY, or in second generation ELT instruments. This will also depend on the context at ESO. Other opportunities for partnerships or R&D projects will certainly occur e.g. instrumentation to measure CMB and foreground polarisation, spectro-polarimeters for the upper atmosphere, and CSUG projects. To a large extent these opportunities will have to fit with our core instrumental expertise, our scientific goals, and will be expected to mostly bring in the required resources through outside funding.

Towards these aims, an organisation with **seven scientific teams** has emerged from our internal discussions (Charm, Exoplanètes, Interstellaire, Odyssey, Sherpas, Spectre, Planéto) and will be in place on July 1, 2019. This reflects in part the growth we have seen in projects and fixed-term contracts. The teams are relatively balanced, each one having 7 to 10 permanent researchers, and up to 10-20 people when including PhD students and postdocs.

- The first evolution is the change of the Cristal R&D transverse axis into the team **Charm**. Integrating scientists doing instrumental research within the scientific teams and the discussions that this prompted was highly appreciated by the Odyssey and Exoplanètes teams. However, the scope of the transverse activity was deemed too broad to be effective. In practice, there was little overlap and too much difference in the level of activity between instrumental research e.g. on radars, submm detection, and high contrast imaging. Furthermore, it was felt that this did not lead to meaningful integration of instrumental research around a common scientific goal; and that instrumental research took a backseat to other scientific objectives when arbitration was solicited from the scientific teams, especially when its purpose is still far removed from immediate application to astronomical instrumentation. This led de facto the Cristal transverse team to being gradually considered on a par with scientific teams but its scope had to be clarified. Charm will focus on optical high angular resolution, high contrast imaging, high resolution spectroscopy. Targeting the characterisation of Earth-like planets will require advances beyond the state-of-the-art on each of these topics in a global approach that combines them all. This is fully in line with the major long-term goals of IPAG. Charm builds upon the long experience of IPAG scientists on these topics and will help promote to the outside world our commitment to this long-term goal.
- The second evolution is the creation of team **Spectre**. IPAG has a strong track record in planetary sciences and in the interstellar medium dating back to LPG and LAOG. Closer integration has been sought ever since the merger of our labs, leading to a first transverse axis in 2011-2015 on the question of the "astrochemical heritage" of Solar system bodies from the interstellar medium. The past years have seen the topic mature, with increased proximity between astrochemical observations of Solar system analogues and measurements of the composition of small bodies in the Solar system. This convergence is clearly recognised by the Planéto and Interstellaire teams; it is at the heart of the ITN ACO that involves scientists from both teams. Discussions led to the conclusion that a strong enough core of scientists wished to create a new independent team combining observational, experimental and theoretical techniques to study the formation and evolution of proto-solar systems. This is intended to give an impetus to the integration of the astrochemical and cosmochemical approaches. Past collaborations between Spectre scientists make us confident that the team will foster new projects, which will successfully build upon the mixed scientific backgrounds in the team.

The organization in teams does not forbid laboratory-scale scientific exchanges. Many research themes are shared across teams, ensuring many opportunities for inter-team collaborations. For example, the physics of accretion disks, the Galactic central black hole, molecular chemistry, transient phenomena, innovative instrumentation, ... In the same way, collaborations between IPAG people and the rest of the scientific community across the world give different structuring levels which are not mutually contradictory. Keeping track formally of all the levels is not mandatory: publications are the witness of IPAG richness.

The **support group** is also expected to evolve. The increase in non-permanent personnel and project-based funding strains its organisation, in a context of dwindling permanent staff. Clearly, one of the challenges that we face is to stabilise the number of permanent staff before we hit the projected number of 23 in 2023 (a 40% decrease in 10 years). Furthermore, somehow, we must find resources to continue hiring staff for the support group on fixed-term contracts to compensate. Failing to do this would jeopardise our involvement in projects, lead us to abandon R&D or innovation, and compromise our capacity to conduct, or even simply host, future projects. The risk is to see IPAG gradually sidelined from the main stage.

- The ***administration*** of the laboratory is an operational imperative. The administrative permanent staff is in need of a redefinition of its missions as large projects now contribute staff, such as a project assistant, a project manager or a platform manager. Increased dematerialisation imposed by CNRS or UGA may see agents lose purpose, as they become cogs in a chain ran elsewhere. These two evolutions are also opportunities for more added-value work in support of IPAG, through continuous training and through skill development thanks to the new non-permanent staff. These challenges will have to be met together with a new administrator, since our current administrator is due to retire during the next contract. This is no small feat given the administrator's key role and impact on the operation of a laboratory.
- ***Computing*** is also an operational imperative. All our hardware main-frame resources will be out-sourced from the lab by the end of 2020: it is a major environmental issue to consolidate IT infrastructure into efficient data centres and also because we have accepted that we do not have the manpower to support in-house computing facilities. OSUG and GRICAD are the main providers of our local frame computing infrastructure. Overall, we always use shared IT facilities (CIMENT, SUMMER, ZIMBRA, ...) when they meet our needs and offer the necessary security guarantees, in line with global policies pursued nationally to pool infrastructure. Our access to these facilities is secured by major contributions to the hardware (machines for ALMA/NOEMA analysis, for the SPIDI and MHDiscs projects), significant amounts of expert engineer's time and user feedback. The latter means we must be active users for fear that our needs will not be heard. The University must also help by providing enough manpower to have a high level of service on these strategic computing facilities. Similarly, encouraged by INSU, we are moving towards pooling ("mutualisation") of System Administration and Network (ASR) and data base management amongst OSUG labs. However, we must keep in-house expertise on instrument software, whose requirements are specific to astronomy and the planetary sciences. These aspects become increasingly important as instruments require more and more "brain" to operate (e.g. Efisoft). We must also consider developing new skills in high-performance computing and data exploration as these increasingly require skills beyond those of a researcher e.g. to adapt our codes to GPU architectures. This may be done in coordination with OSUG and GRICAD. The risk is missing out on the big data and exascale computing revolutions.
- The ***technical services*** are challenged by the multiplicity of projects and partners. The scale of projects now entails long-term commitment and emphasis on sub-systems, with the risk of losing the broader view and the capacity to conduct "flagship" instruments. Securing close collaborations between scientists and engineers on projects does wonders and is certainly a key. We are fortunate to have highly-skilled engineers, with creative force and initiative. What we must improve is our ability to size up, plan and organise better our workload. This is a challenge for the technical director who, in our current organisation, is also expected to follow current and proposed projects, manage the support group, advise the director and, somehow, fulfil his own prior commitments to projects. We are in the process of trying to find other ways to function that will ease these difficult issues.

Overall, the current management team thinks quality can help us face some of these challenges (not all). We have begun implementing the approach with help from INSU. Perhaps time-consuming and difficult to grasp, the first implementations should demonstrate it is rapidly time-saving, with the process bringing clarity and purpose. A goal of our next contract is to see wider understanding, acceptance, and implementation of this continuous improvement approach at IPAG. **Managing the laboratory** could also benefit from this approach. It is an ever-increasing workload, with ever more responsibilities and strains placed by a complex ecosystem on management, particularly the director. One way to do this is to relieve the director from certain tasks that currently fall upon management such as logistics and maintenance. Keeping the position attractive should be a main concern for the lab, for CNRS and for Univ. Grenoble Alpes.